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~~Part IV.~~ 3 The Effects of Dehydration

on the Aerobic and Anaerobic Capacities of Men) Part 3 IV 4

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The effects of dehydration on the aerobic and anaerobic capacities of men.
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Abstract

The effects of dehydration on $\dot{V}_{O_2}$ max, O_2 debt, blood lactate, and temperature regulation of 4 men in exhausting work and recovery were determined. In the dehydration experiments the men were dehydrated by 4.2 to 4.7% of body weight in the morning by working (MR 190 Cal/m^2/hr) in the heat (50 C db, 27 C wb) for 2 to 3 hours. They then rested for about 3 hours in a cool room (24 C) without ingesting any fluid and their responses during an exhausting treadmill run (3 to 6 min) and recovery were determined. Control experiments were carried out without the dehydration. The average times of running to exhaustion were 4.63 and 4.04 min in the control and dehydration experiments respectively. Body temperature, $\dot{V}_{O_2}$ max, O_2 debt and the elevation of blood lactate in the runs were not significantly different in the two experiments. The reduced capacity for running in dehydration was associated with an average increase of 5% in the O_2 requirement per kg of body weight per minute of running time. The small increase in energy requirement was dependent on more rapid accumulation of the O_2 debt during the runs. Depletion of carbohydrate reserves was probably not a contributing factor to the decreased work capacity since the men's metabolic respiratory quotients averaged 0.89 and 0.87 near the ends of the 50-minute aerobic work recoveries following the control and dehydration runs respectively.

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Dehydration, which is accompanied by a decrease in plasma volume, has been found to interfere seriously with temperature regulation of men in hot environments, particularly if they attempt to work in the heat (1, 5). Circulating plasma volume in dehydration is decreased 2.5 to 4 times as much as would be expected if water loss of the plasma were in proportion to the loss by the whole body (1, 2, 6, 8). Normally under condititions of work in the heat a 10 to 20% increase in circulating plasma volume occurs and this facilitates the circulatory adjustments involving large increases in blood flow to the muscles and to the skin (2, 6). When dehydrated men work in the heat, circulation fails in its function of heat transfer from deep tissues to skin as a result of the reduction in plasma volume.

Several investigators have found that dehydration also reduces the capacity of men for severe work in a cool environment (3, 7, 8). Buskirk et al (3) found a consistent reduction, averaging 0.22 liters/min, in $\dot{V}_{O_2}$ max in men dehydrated by an average of 5.7% of body weight. On the other hand, Saltin (7,8) found that dehydration up to 5.2% caused no reduction in $\dot{V}_{O_2}$ max, or in maximal cardiac output, but that substantial reductions in work tolerance and in the ability to elevate blood lactate in exhausting work occurred.

The present study was designed not only to determine the effects of dehydration on the work tolerance and aerobic capacities of men, but to include measurements of the maximal O_2 debt and the efficiency of men performing exhausting work of 3 to 6 minutes' duration in a cool environment.

PROCEDURE

The same subjects (Table 1) were used, and the same general procedure was followed in this study as in Part III of this report.

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Table 1. Physical characteristics and work rates of the subjects. Work rates in the exhausting runs were selected according to the men's abilities. Work rates in recovery were individually selected to raise $\dot{V}_{O_2}$ to about 50% of maximal rates.

Subj.	Age	Ht.	Wt.	B.S.	Run		Recovery work	
	yr	cm	kg	m^2	km/hr	%gr	km/hr	%gr
AC	23	181	74.2	1.95	17.7	6	10.5	0
DC	21	187	73.5	2.00	12.9	7	6.4	7
DL	24	185	67.4	1.90	12.9	8	6.4	8
GF	23	175	78.9	1.95	10.3	9	5.6	9

Each experiment included an exhausting run on the treadmill followed in order by a 50-minute period of aerobic work, and a 35-minute period of rest, all in a cool environment (24 C). O_2 debt and blood lactate concentration were determined and rectal (T_r) and skin (T_s) temperatures were recorded as in Part III. The control experiments were carried out in the afternoon in a cool environment (24 C) as in Part III with the men normally hydrated.

For comparison with the responses of the fully hydrated men in the control experiments they were dehydrated by 4 to 5% of their body weights in another series of experiments. In preparation for these experiments the men came to the laboratory at 8 a.m. after a light breakfast. Wearing only shorts, tennis shoes, and socks, and with thermocouples in place for rectal and skin temperature records they walked on the treadmill (MR 190 Cal/m^2/hr) in the hot room (50 C d.b., 27 w.b., air movement 55 m/min) without drinking water until they reached the planned degree of dehydration. They were weighed on a balance accurate to ±4 grams before starting and at appropriate intervals during the walk in order to follow the course of the dehydration and terminate the exposure when the proper weight loss was reached. It required from 2 to 3 hours work in the heat to dehydrate the men. Following the dehydration period the men rested in a cool room (24°C) in the laboratory. At noon they ate up to 230 grams of food, rich in carbohydrates, but without fluid. The amount of food eaten varied from none to 230 grams, according to individual appetite. At 2 p.m. the thermocouples were replaced on the men and they were weighed again in preparation for the exhausting run and recovery in a cool room (24 C). The dehydration experiments were carried out exactly as in the control experiments.

RESULTS

The men's body temperatures in the experiments are given in Table 2. The mean values of T_r, T_s and T_m at the beginning of the exhausting runs are remarkably similar in the control and dehydration experiments. There were considerable individual variations from the means, especially in T_s, but none of the individual temperatures indicated a thermal state which would interfere with performance in the run, according to the results of the temperature experiments given in Part III of this report. During the aerobic work phase of recovery the rectal temperatures of all men rose to significantly higher levels in the dehydration than in the control experiments. This is not surprising since dehydration is known to reduce blood volume and thus interfere with cutaneous circulation of men performing moderate work in the heat (1,6). The mean rate of decline in rectal temperature during the resting phase of recovery was about the same in the two experiments.

The metabolic changes in the men during the O_2 debt experiments are given in Table 3. Dehydration of the men just before starting the exhausting runs ranged from 4.15 to 4.7% of body weight. In the control experiments they were normally hydrated at the time of the runs. Three of the 4 men failed to continue the runs as long when they were dehydrated as in the control experiments, the average time of running being significantly reduced by dehydration. $\dot{V}_{O_2}$ max values were practically the same in the two runs. In 3 of the 4 men maximal O_2 debts following the runs were about the same in the 2 experiments. In the other man (DC) considerably lower values of O_2 debt and blood lactate were observed in the dehydration experiment than in the control experiment and these differences were related directly to a substantial reduction in running time. The three men whose running times were reduced in dehydration also had lower blood lactates following the runs. DL who was able to force himself to run as

Table 2. Body temperatures of the subject at the end of the warm up walk and at the designated times in the control and dehydration experiments. Room temperature was 24°C in all experiments except the control on AC in which it was 25°C. Symbols T_r, T_s, and T_m represent rectal, mean skin and mean body temperatures respectively.

	Control exp.				Dehydration exp.			
	T_r	T_s	T_m	T_r-T_s	T_r	T_s	T_m	T_r-T_s
Subject AC								
End walk	37.7	32.2	35.8	5.5	37.6	31.8	35.7	5.8
Start run	38.0	32.5	36.1	5.5	37.8	30.2	35.1	7.6
End run	38.1	30.8	35.5	7.3	37.9	30.1	35.2	7.8
Recovery work, 10 min	38.5	32.1	36.3	6.4	38.5	30.3	35.6	8.2
Work, 50 min	38.6	32.5	36.5	6.1	39.2	30.8	36.3	8.4
Rest, 10 min	38.4	33.9	36.8	4.5	38.7	33.5	36.9	5.2
Rest, 35 min	37.7	34.2	36.5	3.5	38.1	34.4	36.9	3.8
Subject DL								
End walk	37.6	28.3	34.3	9.3	37.9	31.0	35.5	6.9
Start run	37.7	29.3	34.8	8.4	38.1	30.6	35.5	7.5
End run	38.0	26.9	34.1	11.1	38.2	26.8	35.5	11.4
Recovery work, 10 min	38.4	29.5	35.3	8.9	38.7	29.8	35.6	8.9
Work, 50 min	38.2	29.6	35.2	8.6	38.7	29.8	35.6	8.9
Rest, 10 min	37.7	32.4	35.9	5.3	38.0	33.0	36.3	5.0
Rest, 35 min	37.0	33.5	35.4	3.5	37.0	34.1	36.0	2.9
Subject DC								
End walk	37.8	30.2	35.1	7.6	37.5	31.3	35.3	6.2
Start run	37.7	29.4	34.8	8.3	37.7	31.6	35.6	6.1
End run	38.0	27.0	34.2	11.0	37.7	29.9	35.0	7.8
Recovery work, 10 min	38.3	29.0	35.0	9.3	38.3	29.8	35.3	8.5
Work, 50 min	38.6	28.6	35.1	10.0	39.1	31.0	36.3	8.1
Rest, 10 min	38.1	31.5	35.8	6.6	38.4	32.2	36.2	6.2
Rest, 35 min	37.3	32.8	35.7	4.5	37.8	32.8	36.1	5.1

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Table 2. (cont'd)

	Control exp. T_r	T_s	T_m	T_r-T_s	Dehydration exp. T_r	T_s	T_m	T_r-T_s
Subject GF								
End walk	37.9	30.7	35.4	7.2				
Start run	37.9	30.8	35.4	7.1	37.3	31.7	35.3	5.6
End run	37.9	28.7	34.7	9.2	37.4	29.5	34.6	7.9
Recovery work, 10 min	38.2	30.2	35.4	8.0	37.8	30.9	35.4	6.9
Work, 50 min	38.5	31.3	36.0	7.2	39.2	30.6	36.2	8.6
Rest, 10 min	38.3	32.4	36.2	5.9	39.2	32.8	36.3	5.4
Rest 35, min	36.8	34.0	35.8	2.8	38.0	33.8	36.7	4.4
Mean Values, all subjects								
End walk	37.8	30.4	35.2	7.4	37.7	30.8	35.5	6.9
Start run	37.8	30.5	35.3	7.3	37.7	31.0	35.4	6.7
End run	38.0	28.4	34.6	9.7	37.8	29.1	35.1	8.7
Recovery work, 10 min	38.1	30.2	35.5	8.2	38.4	30.1	35.5	8.3
Work, 50 min	38.5	30.5	35.6	8.0	39.1	30.6	36.1	8.5
Rest, 10 min	38.4	32.6	36.2	5.6	38.6	32.9	36.4	5.7
Rest, 35 min	37.2	33.6	35.9	3.6	37.7	33.8	36.4	3.9

Table 3. Metabolic adjustments of men in exhausting runs and recoveries in control and dehydration experiments. The O_2 debt following the run is the sum of excess O_2 consumed during the exercise phase of recovery plus the O_2 debt in the resting phase.

$$O_2 \text{ requirement in liters/min} = \frac{O_2 \text{ cons. in run} + O_2 \text{ debt}}{\text{time of run in minutes}}$$

Subject	AC			DL			DC			GF			Mean, all subj.		
		Recovery			Recovery			Recovery			Recovery			Recovery	
	Run	Work	Rest	Run	Work	Rest	Run	Work	Rest	Run	Work	Rest	Run	Work	Rest
CONTROL EXPERIMENT															
Time, min	4.0	50	35	6.0	50	35	4.5	50	35	4.0	50	35	4.63	50	35
V_{O_2} liters/min	4.42	2.28	0.278	3.56	1.82	0.303	3.48	1.86	0.267	3.38	2.03	0.293	3.71	2.00	0.285
O_2 cons., liters	15.1			19.4			14.2			11.4			15.1		
O_2 debt, liters	10.2	8.1	2.1	6.26	4,84	1.42	7.75	5.74	2.01	6.39	5.0	1.39	7.65	5.92	1.73
O_2 req., liters/min	6.33			4.28			4.88			4.46			4.99		
ml/kg/min	85.4			63.1			66.3			56.7			67.9		
Lactate, mg%	169.4	13.6	11.5	103.4	4.3	7.9	105.1	10.7	12.0	120.8	7.0	7.2	124.7	8.9	9.7
DEHYDRATION EXPERIMENT															
% dehydr.	-4.23			-4.16			-4.7			-4.15			-4.31		
Time, min	3.67	50	35	6.0	50	35	3.5	35	35	3.0	50	35	4.04	50	35
V_{O_2} liters/min	4.39	2.30	0.300	3.64	1.87	0.325	3.25	1.90	0.270	3.42	2.00	0.320	3.68	2.02	0.305
O_2 cons., liters	14.1			19.4			10.1			9.03			13.2		
O_2 debt, liters	9.73	8.3	1.43	6.30	4.93	1.37	5.04	3.37	1.66	6.87	5.39	1.48	6.99	5.50	1.49
O_2 req., liters/min	6.5			4.28			4.36			5.3			5.11		
ml/kg/min	90.9			65.7			62.6			67.0			71.5		
Lactate, mg%	160	12.3	6.2	106.2	7.3	6.6	97.8	10.0	10.5	103.8	13.8	7.6	117.0	11.0	6.8

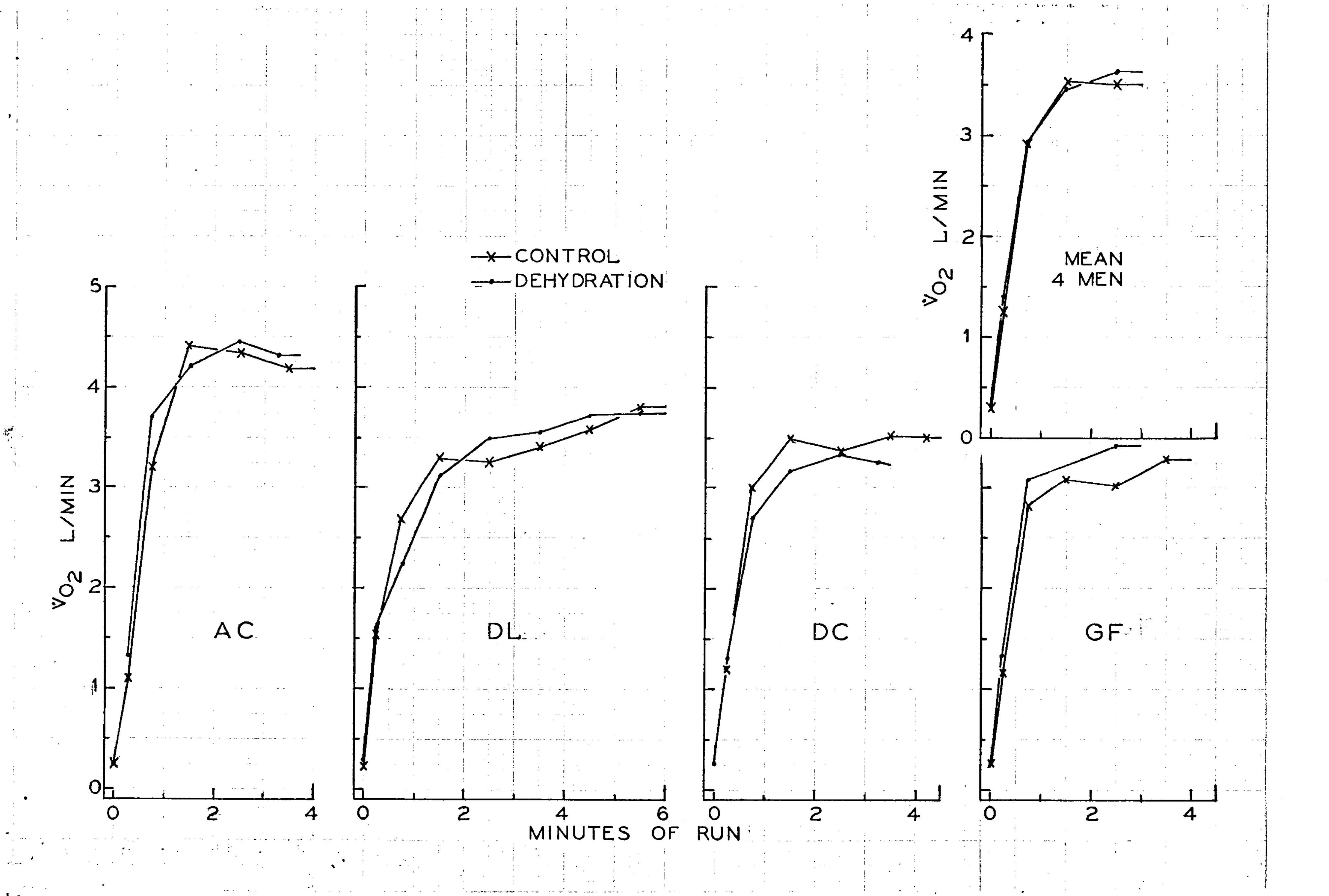
long in the dehydration as in the control experiment accumulated a higher lactate in the former. The average O_2 requirement per minute of running time was not significantly different in the two runs. However, since the men's body weights were reduced in the dehydration experiments, the average O_2 requirement/min/kg of body weight was about 5% higher in those experiments than in the controls.

DISCUSSION

The most significant effect of dehydration on performance in the exhausting runs was a reduction in the time the men could continue the runs before they reached exhaustion. This decrease in endurance was dependent, at least in part, on decreased efficiency as indicated by a small (5%) increase in O_2 requirement/kg/min of running time. Since the average $\dot{V}_{O_2}$ max and the amount of O_2 debt accumulated in the runs was the same, the increased O_2 requirements of the men in dehydration experiments were dependent on increments in the rates of accumulating the O_2 debt. On the average the men accumulated about the same O_2 debts in both runs, but since the average time of running was decreased in the dehydration experiments, the build up of the O_2 debt was faster in those experiments than in the controls. The decrease in efficiency in dehydration was probably not dependent on depletion of the men's carbohydrate reserves in the morning walks preceeding the runs. Evidence for this is that their metabolic respiratory quotients during steady states near the end of the exercise recoveries were only slightly lower in dehydration (0.87) than in the control experiments (0.89).

Our data showing no reductions of $\dot{V}_{O_2}$ max when the men were dehydrated confirm previous results of Saltin (5,6). Furthermore, dehydration did not decrease the rate of elevating the O_2 consumption during the first 2 or 3 minutes of the runs (Fig. 1). The retention of

Fig. 1. $\dot{V}O_2$ of the men during the exhausting runs. Mean values indicate that neither the rate of increase in the first two minutes nor the $\dot{V}O_2$ max were significantly altered by dehydration.



the maximal capacity for increasing O_2 consumption in exhausting work indicates that in dehydration the men were able to make adequate compensatory vasoconstrictor responses in the skin and viscera, and thus shunt most of the blood flow to the working muscles. Another factor which probably helped in this response was the hemoconcentration which occurred in dehydration; the men's hematocrits at the start of the runs averaged 46.6% in the control and 49.0% in the dehydration experiments. This increase in O_2 capacity of the blood could compensate for a moderate reduction in maximal cardiac output which might be expected to occur with the reduction of blood volume which occurs in dehydration. However, as stated above, Saltin (6) has found little change in maximal cardiac output of men in dehydration.

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